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PSEUDOLEUCITE FROM PLUTONIC ALKALIC ROCK-CARBONATITE COMPLEXES

DAVID H. WATKINSON
Department of Geology, Carleton University, Ottawa, Canada

Abstract

Intergrowths of nepheline and K-feldspar occur in three forms in alkalic rock-carbonatite complexes of northern Ontario; the intergrowths have (1), hexagonal outlines in fine-grained ijolite and malignite of the Nemegosenda Lake complex, (2), rounded outlines in feldspar-rich malignite in the Lackner Lake complex, and (3), irregular outlines and are interstitial to nepheline, pyroxene, garnet and wollastonite in urtite of the Prairie Lake complex. Electron microprobe analyses of the intergrowths and of the constituent nepheline and K-feldspar confirm petrographic interpretation that they are pseudoleucite formed by subsolidus breakdown of highly sodic leucite. The variety of morphology and mineral association is consistent with different crystallization paths in petrogeny's residua system. The chemical compositions of the intergrowths imply that highly sodic leucite precipitated from alkalic magmas at $P(H_2O)$ much less than P(total).

Introduction

Nepheline-feldspar intergrowths in rocks of the ijolite series of plutonic alkalic rock — carbonatite complexes at Prairie Lake, Lackner Lake and Nemegosenda Lake, Ontario (Fig. 1) are similar petrographically to pseudoleucite formed by subsolidus breakdown of sodic leucite (Fudali 1963). Davidson (1970) concluded that similar intergrowths from the Kaminak Lake complex formed by cotectic precipitation of nepheline and feldspar from residual alkalic magma, although he did not entirely rule out an origin by breakdown of sodic leucite. Similar intergrowths have

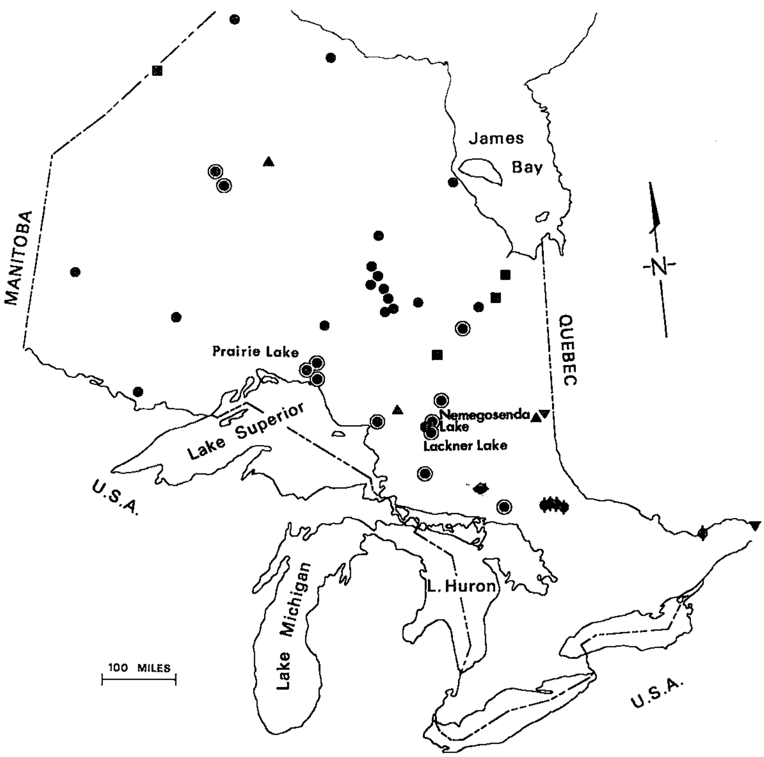

FIG. 1. Location of alkalic rock-carbonite complexes in Ontario.

been reported from plutonic rocks of the Ice River complex (Allan 1914), Magnet Cove complex (Erickson & Blade 1963) and Callander Bay complex (Ferguson & Currie 1972), as well as many volcanic (Fudali 1963) and hypabyssal rocks (Tempelman-Kluit 1969).

Scarfe *et al.* (1966) state that leucite is common in volcanic rocks and virtually unknown in plutonic rocks. On the basis of their experimental evidence they suggest that there is a very limited stability range for precipitation of leucite in plutonic rocks because:

1. The composition of plutonic rocks is not appropriate.
2. Reaction of leucite to K-feldspar plus kalsilite restricts leucite to low pressure — high temperature conditions (curve A, Fig. 2).
3. Pressure of water further restricts the stability by decreasing the high temperature range at which leucite may precipitate from liquid (curve B, Fig. 2), and
4. Presence of sodium decreases the stability range by lowering the melting temperature and raising the breakdown temperature of leucite.

Interpretation of the intergrowths in plutonic rocks as pseudoleucite rather than cotectic precipitates thus permits one to draw conclusions on the physical and chemical conditions under which these plutons crystallized.

Geology and Petrography

Field and petrographic studies on many of the alkalic rock complexes of northern Ontario have revealed intergrowths of K-feldspar and nepheline in the Prairie Lake, Lackner Lake and Nemegosenda Lake complexes (Fig. 1). These are circular, concentric, ring-like complexes intruded about 1,100 million years ago into rocks of the Superior structural province. They are all unmetamorphosed.

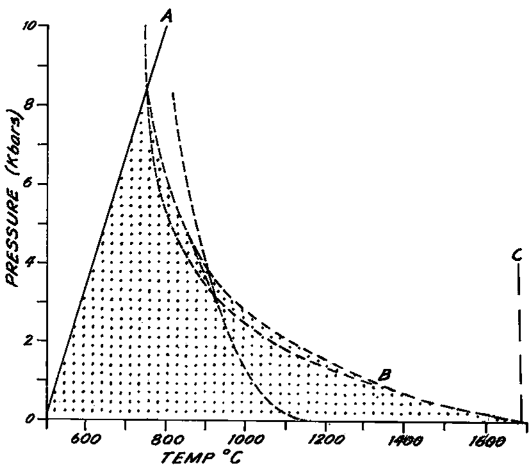

FIG. 2. PT projection of univariant relations involving leucite in the "system" $KAlSiO_4$-$KAlSi_3O_8$-H_2O after Scarfe, Luth & Tuttle (1966). Stability of leucite in the presence of a free aqueous phase is stippled. A- sanidine + kalsilite ⇌ leucite; B- melting curve of leucite, $P(H_2O) = P(\text{total})$; C- anhydrous melting of leucite.

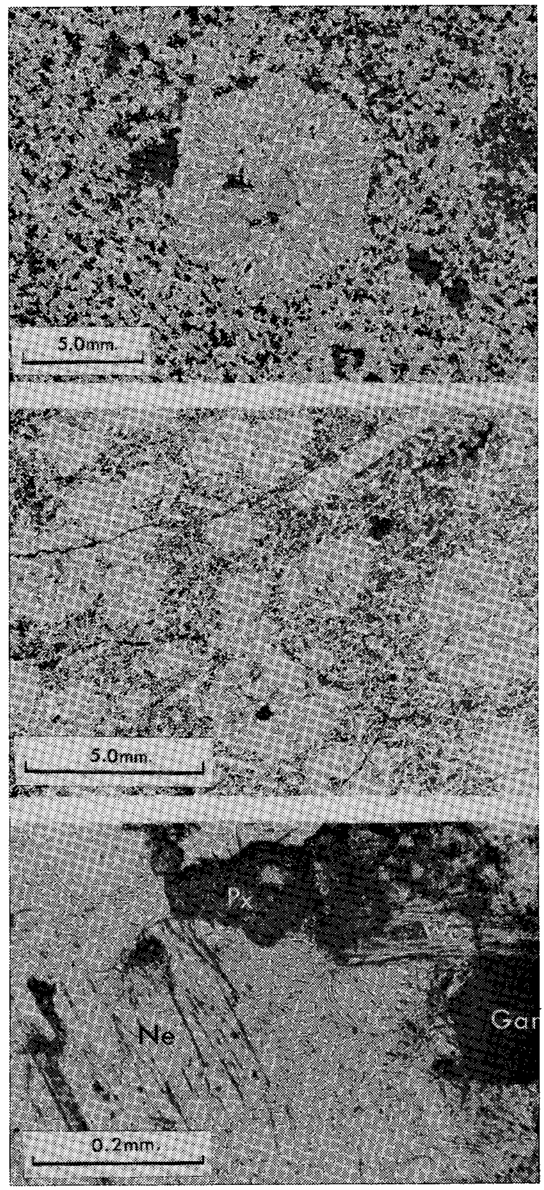

FIG. 3. Pseudoleucite from Nemegosenda Lake malignite.

FIG. 4. Round to irregularly shaped pseudoleucite and K-feldspar in fine-grained malignite, Lackner Lake.

FIG. 5. Prairie Lake pseudoleucite interstitial to nepheline (Ne), sodic pyroxene (Px), wollastonite (Wo), and garnet (Gar).

Lackner Lake complex

The Lackner Lake pluton (Hodder 1961; Parsons 1961), is dominantly composed of nepheline syenitic rocks with lesser amounts of ijolite-malignite at the present exposure level. Magnetite-apatite rocks and carbonatite are of minor areal extent. Nepheline-feldspar intergrowths occur commonly in the malignitic rocks as rounded aggregates as large as 1 cm in diameter; some have polygonal outlines (Fig. 4). Grains of dark biotite occur in the centres of some intergrowths. The aggregates as well as K-feldspar are enclosed in a fine-grained groundmass of aegirine, nepheline, biotite, K-feldspar, apatite and ilmeno-magnetite.

Nemegosenda Lake complex

The Nemegosenda Lake complex (Parsons 1961) is a similar intrusion with less ijolite-malignite, minor carbonatite, and more syenite and lamprophyric units. Some malignite contains intergrowths of K-feldspar and altered nepheline with hexagonal and irregular outlines (Fig. 3). enclosed in a groundmass of altered nepheline, feldspar, pyroxene, biotite and ilmeno-magnetite. Some dark biotite occurs within the aggregates.

Prairie Lake complex

The Prairie Lake intrusion (Watkinson 1973) consists mainly of carbonatite with inner, partial rings of ijolite-melteigite and urtite. The nepheline-feldspar intergrowths in urtite are interstitial to abundant nepheline and minor garnet, sodic pyroxene, wollastonite and trace biotite, ilmeno-magnetite, sphene and apatite (Fig. 5). Chemical compositions of these minerals are given by Watkinson (1973). The polygonal outlines of some intergrowths are suggestive of an origin by breakdown of sodic leucite, although the interstitial and very fine-grained nature of some intergrowths might be interpreted to have formed by quenching of late-stage liquid as Davidson (1970) had concluded.

Electron Microprobe Analysis

The intergrowths were quantitatively analyzed by the electron microprobe using a highly defocussed beam; a focussed beam of approximately 1 micron diameter was used for nepheline and K-feldspar analyses. Specimen currents in the range 30-50 nanoamps and kilovoltages of 15 and 10 were used; the lower values gave superior analyses. Standards used were analyzed jadeite, K-feldspar, albite, halite and synthetic fluorphlogopite. The x-ray data were computer-corrected using the computer program EMPADR 7 (Rucklidge 1967). The coarse-grained intergrowths from Lackner Lake were scanned across the defocussed beam at five microns per second. The resultant analysis is the average of 76 sets of ten-second counts for Na and K and 48 sets for Al and Si. A standard albite analyzed in the same manner gave the following results: Na_2O 11.60, Al_2O_3 19.77, SiO_2 68.58, sum 99.95%.

The results are given in Table 1 and projected onto petrogeny's residua system in Figure 6.

Pseudoleucite

In addition to the elements shown in Table 1, the Prairie Lake pseudoleucite aggregates also contain 0.26% CaO, 0.09% MgO, 0.09% Na_2O, 0.02% TiO_2, and 0.05% BaO; giving a sum of 99.31%.

The Lackner Lake pseudoleucite contains in addition 0.43% Fe_2O_3 (all Fe calculated as Fe_2O_3), 0.51% CaO, 0.05% MgO, 0.03% TiO_2 and 0.02 MnO. This totals 97.13%, which is slightly low. However, the analysis did not take into account the small amount of dark biotite which is occasionally revealed in sections cut through pseudoleucite. In addition to nepheline and K-feldspar, biotite may be a minor breakdown product of leucite which originally may have contained iron in the aluminum position. This may explain why the analyses do not project directly onto lines joining the analyses of the constituent felsic phases.

TABLE 1. ELECTRON MICROPROBE AVERAGE ANALYSES OF PSEUDOLEUCITE AND CONSTITUENT NEPHELINE AND FELDSPAR.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
SiO_2	56.24	54.57	41.86	41.51	41.01	43.67	43.57	63.59	63.92	60.70	65.52	64.23	64.05
Al_2O_3	23.14	23.88	34.17	34.33	35.27	33.05	33.30	18.25	18.08	21.26	18.70	18.26	18.17
Na_2O	5.03	7.45	15.99	16.45	14.76	15.80	15.60	1.17	1.50	0.32	0.64	0.82	0.74
K_2O	14.39	10.19	8.09	7.95	8.40	6.68	6.52	15.85	14.62	15.08	17.76	14.93	15.57
TOTAL	99.34	96.09	100.11	100.24	99.40	99.20	98.99	98.86	98.12	97.36	102.62	98.24	98.53

1,2, pseudoleucite from Prairie Lake urtite, PL 012, and Lackner Lake malignite LL007; 3,4,5, nepheline from urtites PL 212, PL 171 and PL 399; 6,7, nepheline in groundmass and in pseudoleucite, LL007; 8,9, feldspar in groundmass and in pseudoleucite, LL007; 10,11 feldspar in PL 399, PL 171; 12, 13 feldspar in NL 13-3 groundmass and pseudoleucite

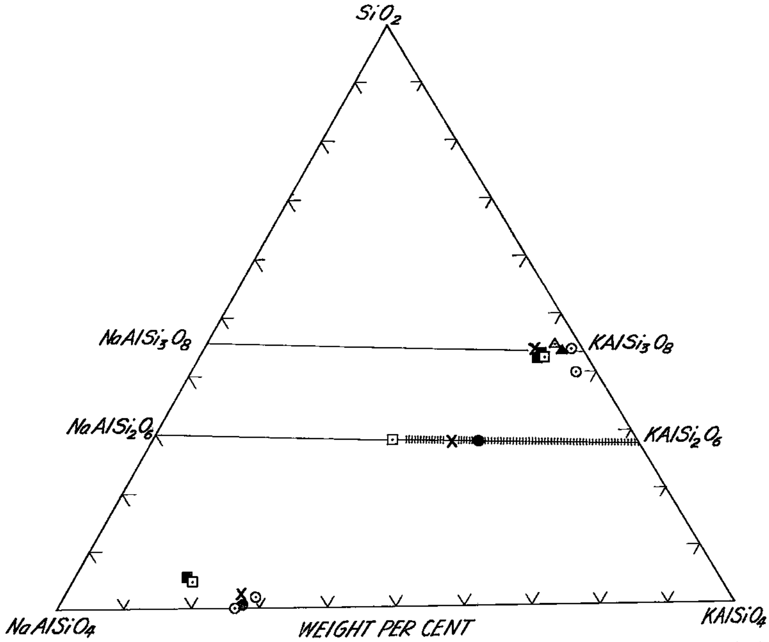

FIG. 6. Projection of analyses onto petrogeny's residua system. Filled symbols — intergrowth constituents; open symbols — groundmass constituents. Squares — Lackner Lake complex, triangles — Nemegosenda Lake complex, circles — Prairie Lake complex, crosses — Kaminak Lake complex.

The pseudoleucite analyses correspond to compositions of highly sodic leucite and project near the limit of Na for K substitution in leucite at one atmosphere (Schairer 1957).

Feldspar

The feldspar from all three complexes is potassium feldspar with less than 1.5% Na_2O. One very narrow partial albite rim was observed on a K-feldspar from Lackner Lake. Within a polished thin section the precision of analysis was very good; for example, the ranges in weight per cent for seven grains from the Nemegosenda malignite were K_2O 14.60-15.94; Na_2O 0.06-0.84; Al_2O^3 18.13-18.29; and SiO_2 63.63-64.61. The highest K and lowest Na values were from feldspar in intergrowths.

Nepheline

Nepheline in the Prairie Lake urtite projects very close to the $KAlSiO_4$-$NaAlSiO_4$ join whereas nepheline from the Lackner Lake malignite is more silicic and sodic. Analyses of the Prairie Lake nephelines PL 171 and PL 012 contain in addition the following oxide weight percentages respectively; CaO 0.11 and 0.05, BaO 0.03 and 0.03, MnO 0.04 and 0.09, MgO 0.11 and 0.09. Nepheline in the Nemegosenda Lake rock was altered and was not analyzed.

DISCUSSION

Davidson (1970) has given an excellent summary of the possible modes of origin of nepheline-feldspar intergrowths from Kaminak Lake. His conclusion, however, that they form by cotectic crystallization, is not acceptable for the intergrowths described above. The presence of polygonal outlines and the restriction of chemical composition to that of leucite crystalline solutions is compelling evidence for subsolidus breakdown of sodic leucite. The round aggregates may represent leucite that was partialy resorbed by the magma; analogous resorption occurs at the peritectic point in petrogeny's residua system where leucite, in equilibrium with nepheline and liquid, reacts with the liquid to produce feldspar. In the Lackner Lake rocks, round pseudoleucite coexists with K-feldspar megacrysts (Fig. 4). Interstitial pseudoleucite of the Prairie and Kaminak Lake rocks might be indicative of late-stage precipitation of leucite from a liquid that has already generated abundant nepheline and other minerals.

Differing crystallization paths in petrogeny's residua system which might generate these three differing habits of pseudoleucite have been described by Davidson (1970, p. 202-3). They all are compatible with precipitation of sodic leucite and subsequent subsolidus breakdown to pseudoleucite as described by Fudali (1963).

The problem in this genetic interpretation of the intergrowths is that highly sodic leucite cannot precipitate from plutonic liquids for which $f(H_2O)$ is high by analogy with the experimental study of Fudali (1963). On the other hand, anhydrous liquids would presumably have extremely high liquidus temperatures (Fig. 7). Tempelman-Kluit (1969) suggested that the highly sodic nature of pseudoleucite is the result of metasomatism of the leucite breakdown products by sodic aqueous solutions. He acknowledged that the occurrence of pseudoleucite without hydrous mineral constituents would be a serious argument against his hypothesis. The anhydrous nature of the Lackner and Prairie Lake pseudoleucite suggests that such metasomatism is unlikely to have been effective, as is a possible origin by breakdown of potassic analcite, a hydrous mineral, (Ferguson & Currie 1972). The generally anhydrous nature of the mineralogy, lack of extensive alteration of intergrowth as well as groundmass nepheline, and paucity of pegmatites suggest that the Prairie and Lackner Lake complexes, especially, might have precipitated from magmas of low $f(H_2O)$. The Nemegosenda Lake pseudoleucite has altered nepheline and occurs in malignite originally mapped as fenite (Parsons 1961) ; there are as yet insufficient data on these rocks to further speculate on their genesis.

It can be seen in Figure 7 that the maximum possible $NaAlSi_2O_6$ content of leucite is a function of the temperature of intersection of curves involving melting relations with the solubility curve for $NaAlSi_2O_6$ in $KAlSi_2O_6$. At high water fugacity the curves involving melting intersect the solubility curve at low temperature. However, at low fugacities of H_2O, such as is shown in the 1 atmosphere experimental data (Fig. 7) and at high total pressure, the maximum solubility is great and in the range of the natural pseudoleucite compositions (Fig. 6).

The sodic nephelines and highly potassic feldspars in these rocks are consistent with equilibria at moderate to high temperature and low $f(H_2O)$, based on high pressure studies in petrogeny's residua system by Morse (1968, 1970) as well as with those at low pressure [$P(H_2O) = P(\text{total})$] and low temperature (Fudali 1963; Hamilton 1961). Data from studies at $P(H_2O) < P(\text{total})$ and in more complex systems are necessary to infer, independantly, conditions of pressure, temperature or water fugacity from compositional data on these minerals.

Thus if $f(H_2O)$ is low during plutonic crystallization, if $P(\text{total})$ is high, and if the presence of other species which dissolve in the liquid depress the melting relationships very little, highly sodic leucite may precipitate. Analogous precipitation and stability of leucite occurs in the area between curves A and C in Figure 2.

Abundance of H_2O in alkalic magma is notable in most complexes as is evident by the abundance of hydrous minerals, ubiquitous alteration of minerals (such as nepheline), fenitization, presence of fluid inclusions and explosively brecciated structures. One manner in which the content of H_2O (and other so-called mineralizers) may be depleted in the magma is by their strong fractionation into a coexisting, immiscible liquid phase. Such a phase might be represented by carbonatite in these complexes which shows spatial relationships to rocks of the ijolite series. Immiscibility of carbonatite and silicate liquids has been experimentally verified (Koster van Groos & Wyllie 1968). However, there is little evidence for natural immiscibility of carbonatite and silicate magmas other than the occurrences of carbonate-rich ocelli in hypabyssal silicate rocks (Ferguson & Currie 1972).

Carbonatite and ijolitic rocks are segregated on a gross scale at Prairie Lake and in other carbonatite complexes (Watkinson 1973) and this might result from an immiscible relationship. There are two differentiation trends in the Prairie Lake rocks which are defined on the general petrography and on the basis of pyroxene compositions ; these are the ijolite-carbonatite and ijolite-

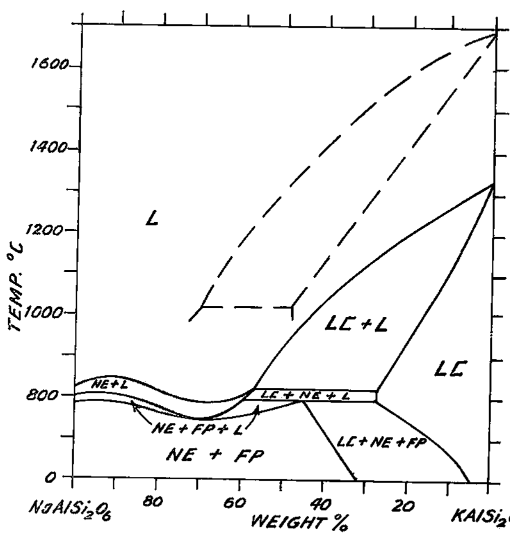

FIG. 7. The join $NaAlSi_2O_6$-$KAlSi_2O_6$-H_2O at 1 kbar after Fudali (1963). Dashed lines are for the anhydrous system at 1 bar.

urtite sequences. These might be explained, however, by fractionation of two pulses of ijolitic magma, one rich and the other poor in H_2O and CO_2. Neither interpretation has been completely substantiated.

Further field study, or appropriate experimentation is necessary to permit a better evaluation of the possibility of liquid immiscibility and subsequent fractionation of water away from the phase which potentially may precipitate sodic leucite.

Conclusions

The nepheline-K-feldspar intergrowths in these plutonic complexes are pseudoleucite. Their compositions project onto the leucite solid solution join and their habits are consistent with differing paths of crystallization of ijolite-series magma by analogy with results of the experimental study of Fudali (1963).

Their concurrence in plutonic rocks suggests that the magmas crystallized under high P(total) and had a low $f(H_2O)$ at the time of precipitation. The occurrence of interstitial pseudoleucite in "residual" liquid giving rise to urtite might have low H_2O content if water was strongly fractionated into a coexisting, immiscible carbonatite magma.

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